

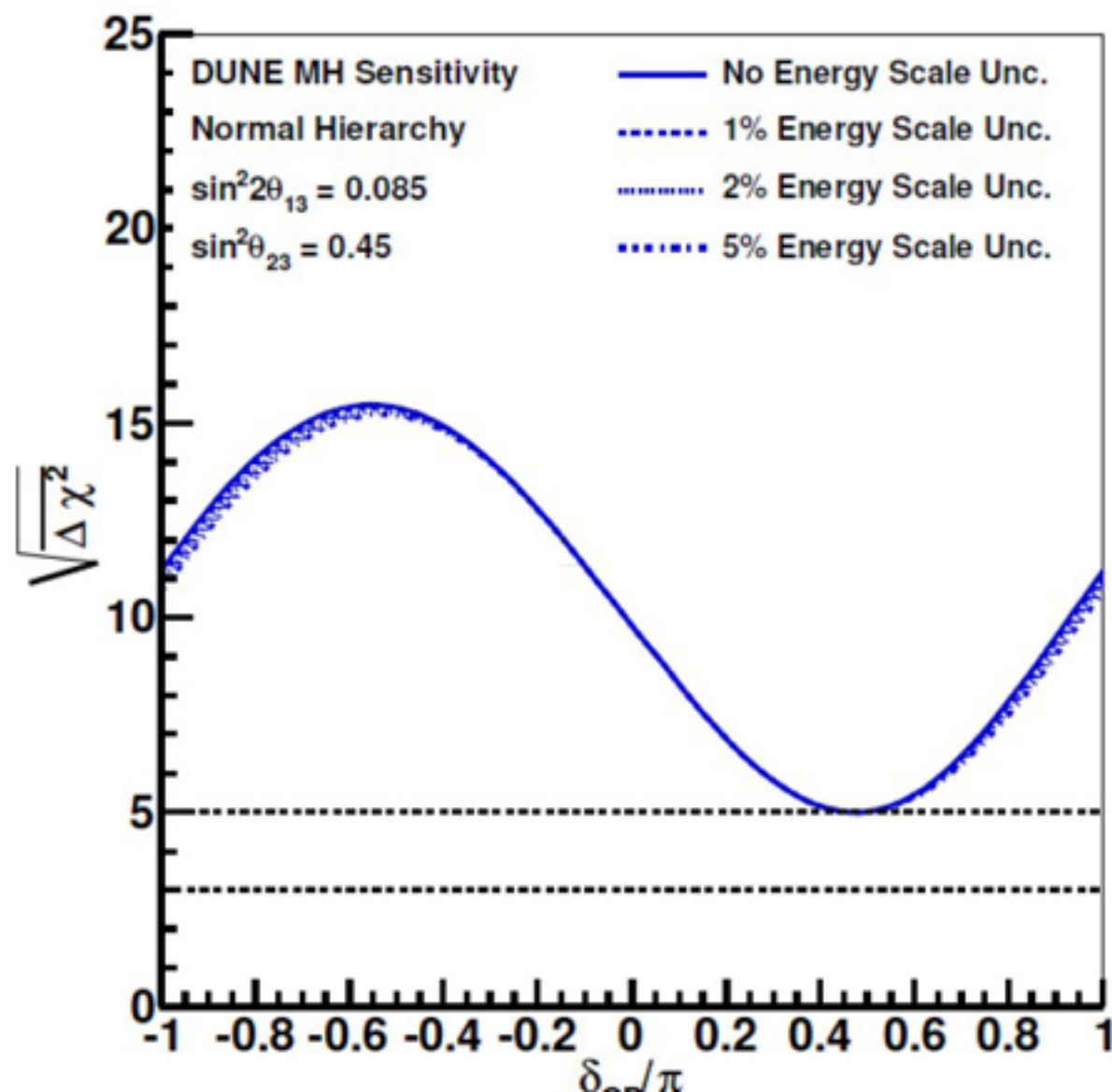
Laser systems for calibration on DUNE

- Why the E field is important
- Systems which are the most independent measure the E field
 - Configuration options: photoelectron based on ionization (“laser” based)? Penetrate the field cage or not?
- Dual Phase considerations

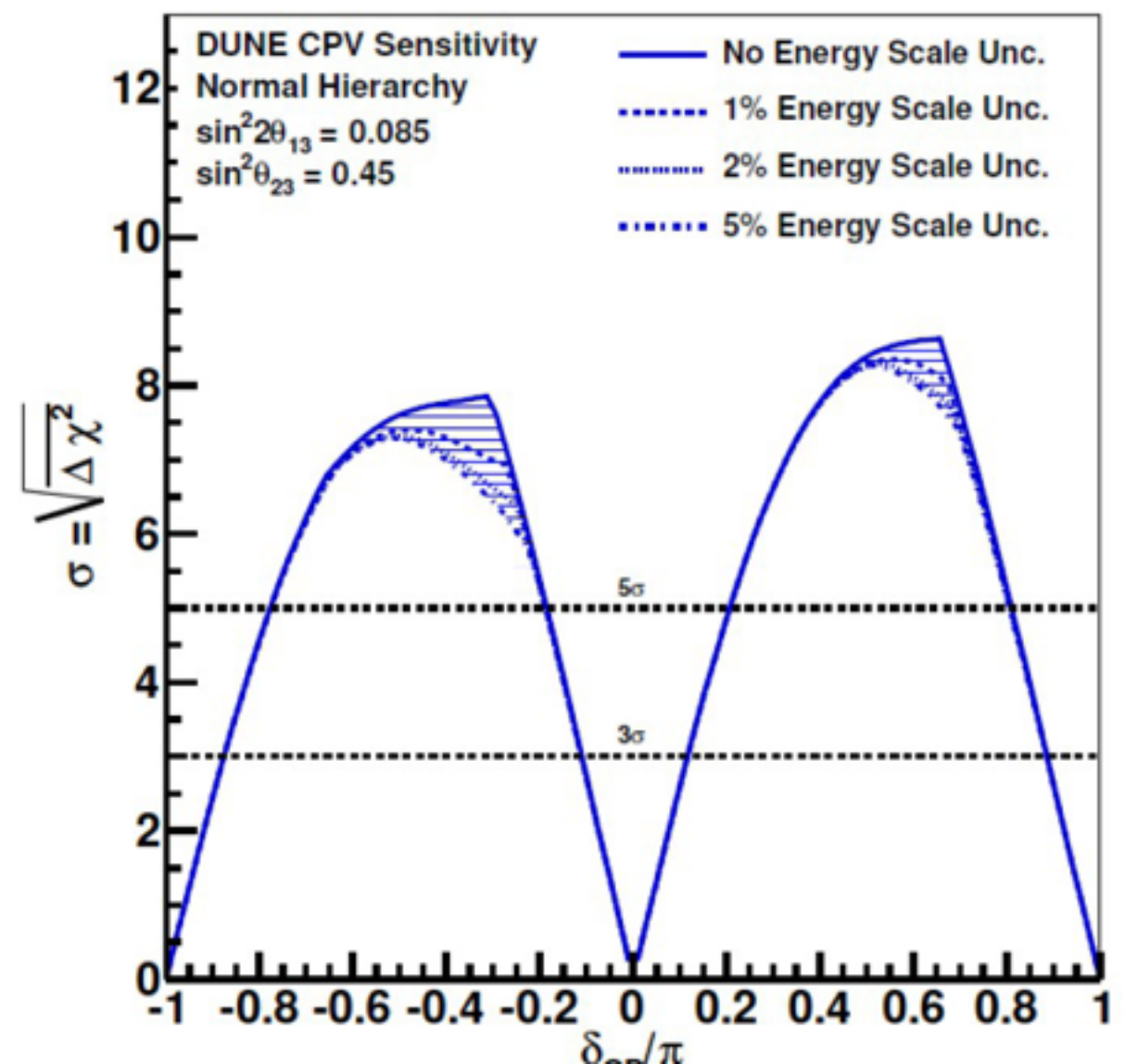
Issue: Unprecedented Physics Requirements of DUNE

CDR: Uncertainty of 2% on energy scale is already important to physics goals; calibration must be $<2\%$

Mass Hierarchy Sensitivity

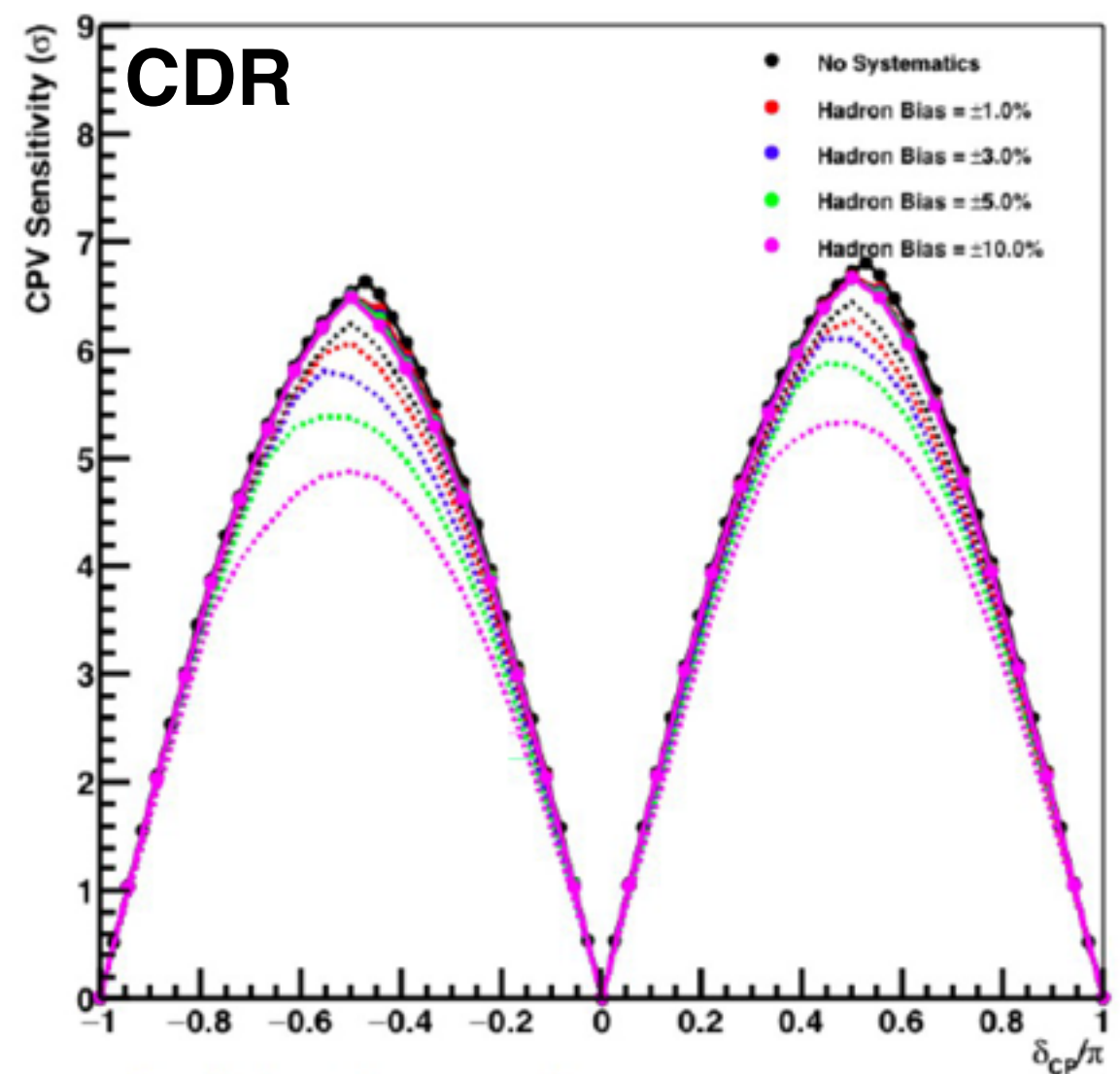
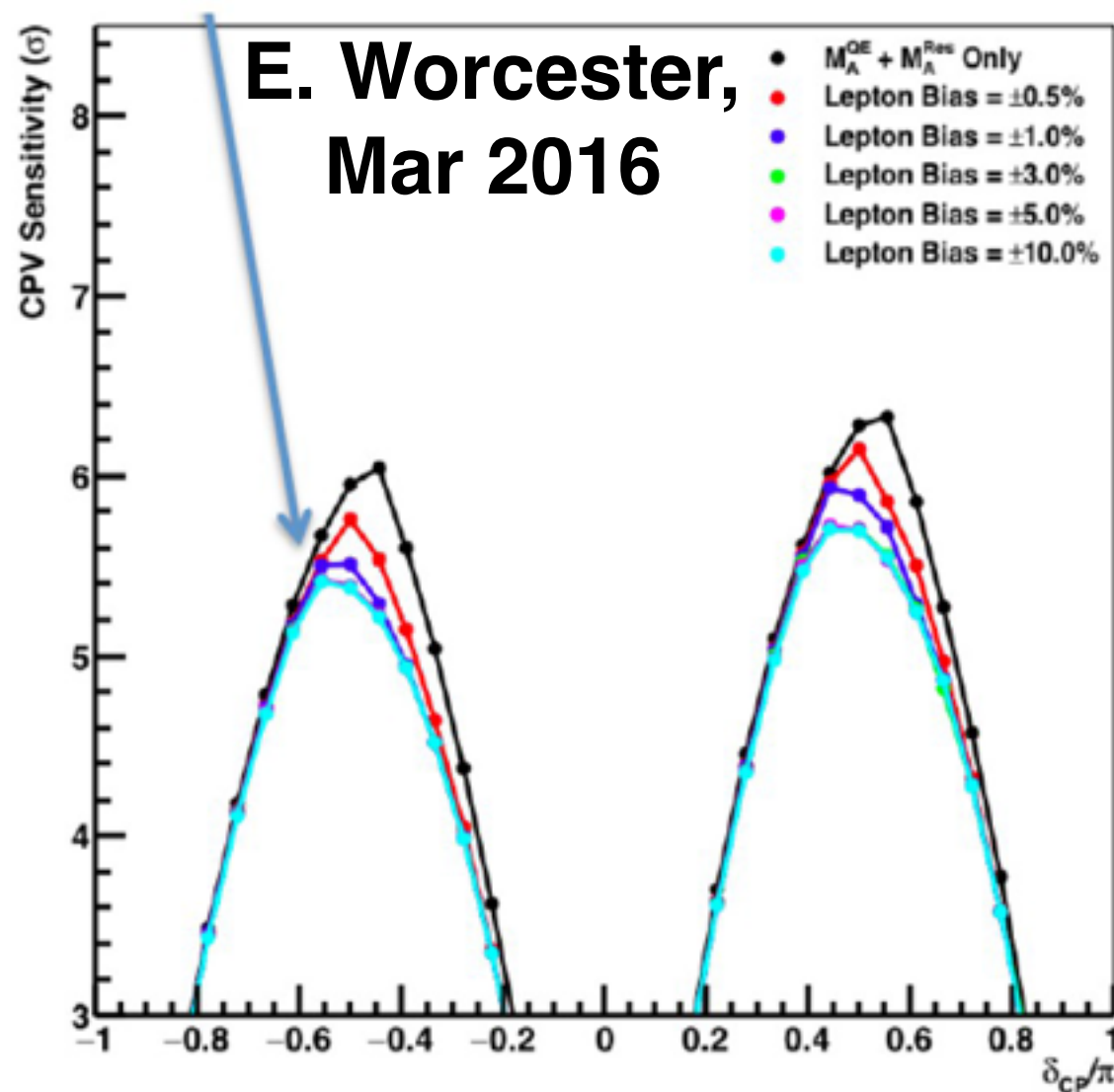


CP Violation Sensitivity



Issue: Unprecedented Physics Requirements of DUNE

1% Lepton energy bias is already important to physics goals; calibration must be $<1\%$



Solid = 4 sample
Dashed = ν_e only

Critical role of electric field

- E-field variations from existing LArTPCs (MicroBooNE, ICARUS) has not agreed with expectations
- A lot of calibration parameters depend on E field (e.g. drift velocity, track distortions, recombination)
- A 5% uncertainty in the field can lead to about $\sim 1\%$ bias in energy

Sources of E field distortions

- Detector component mis-alignment, structural deformations
- Space charge (at cathode, due to fluid flow, cosmics, DP at gas-liquid interface)
- Resistor failure in field cage, resistivity not uniform, voltage variation in cathode
- Penetration of the field cage

Size of these effects prepared by Bo Yu, Mike Moone summarized later; Effects may add in quadrature

Systems used previously

Laser systems in TPCs:

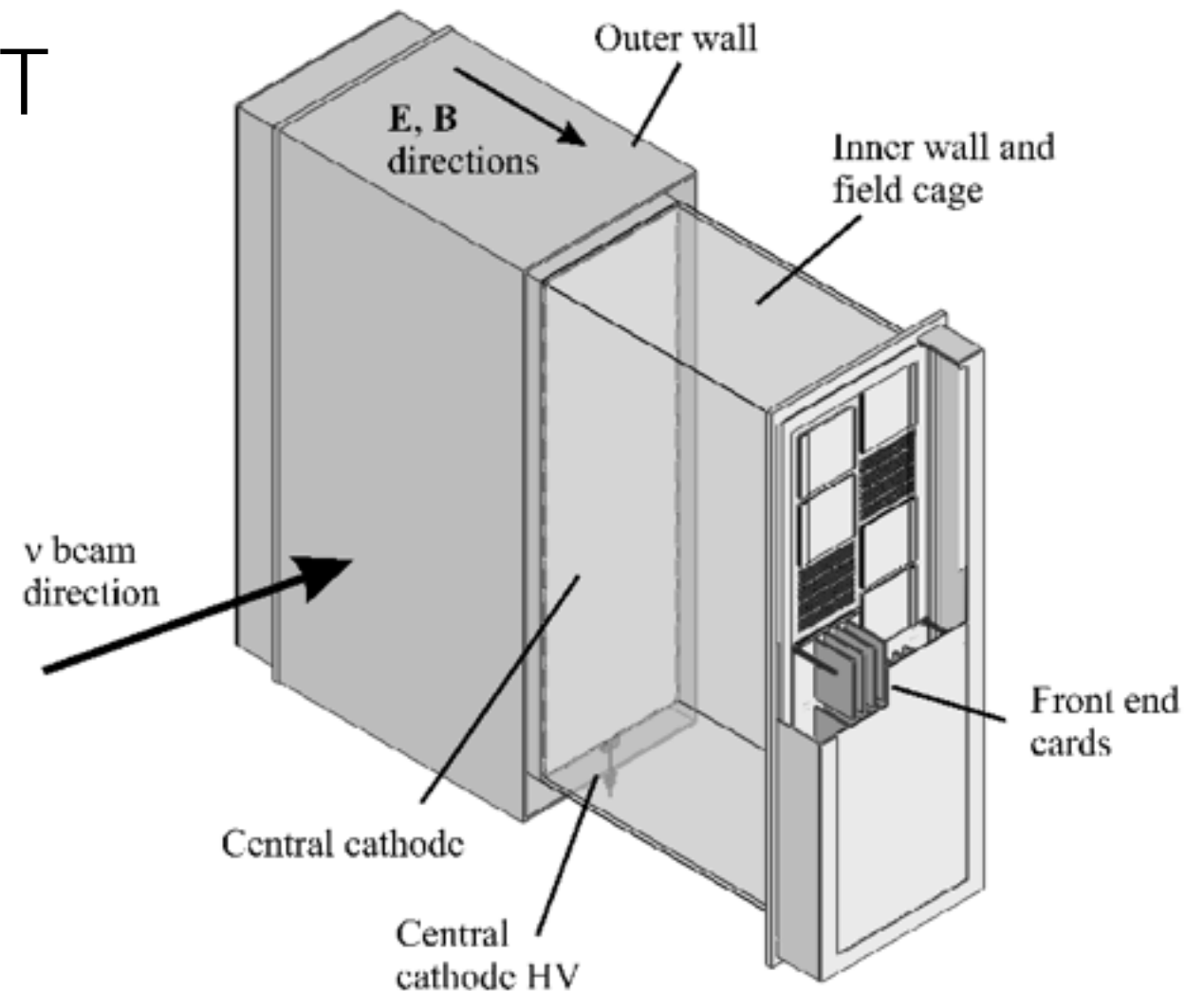
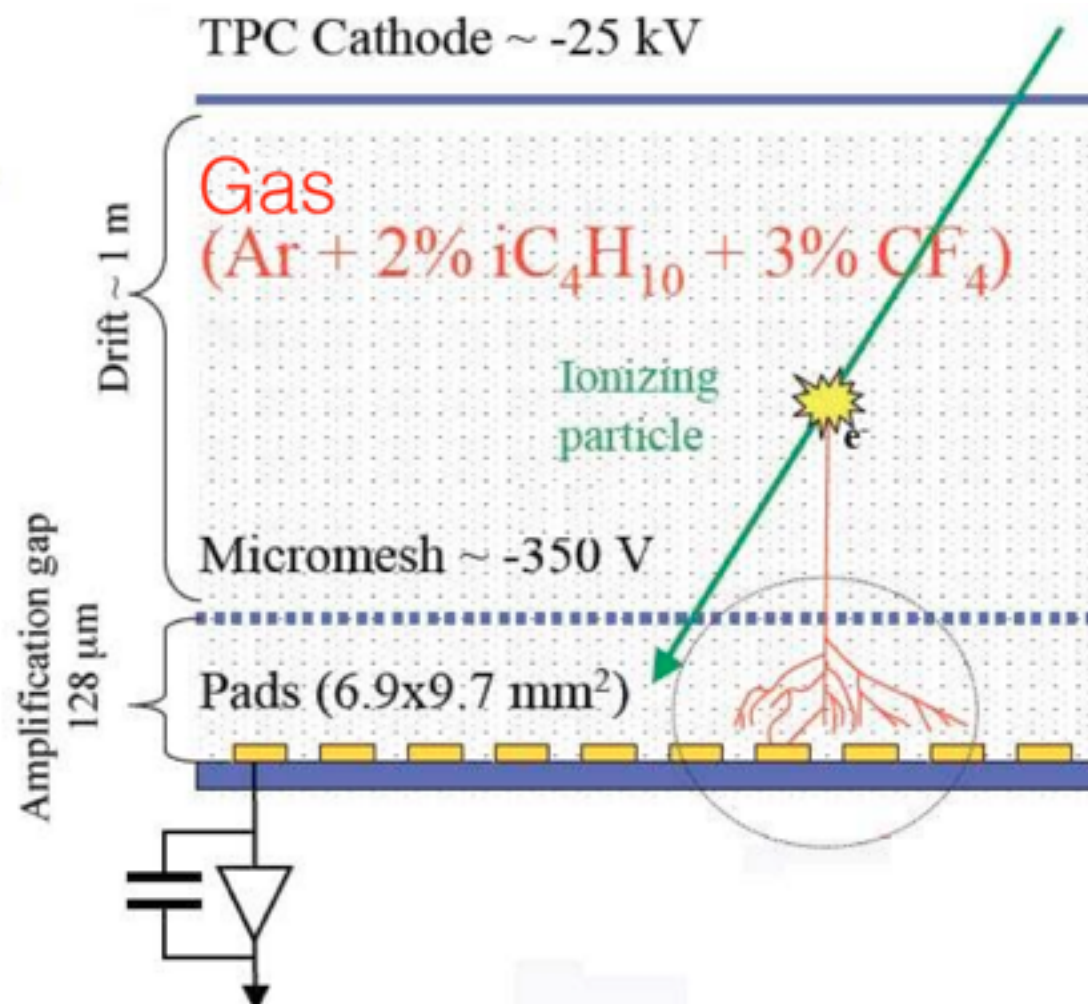
- ICARUS: alignment via survey, measurements of modules
- MicroBooNE/SBND: JINST 4:P07011,2009, J.Phys. 12 (2010) 113024
- T2K - Nucl. Instrum. Meth. A 637, 25 (2011)
- mini-CAPTAIN, CAPTAIN: similar concept to uB/SBND

Other Laser systems: Reactor experiments (though did not find direct applicability here)

T2K TPC system

3 Gas TPCs operated in a 0.2T field measure particles from neutrino interactions

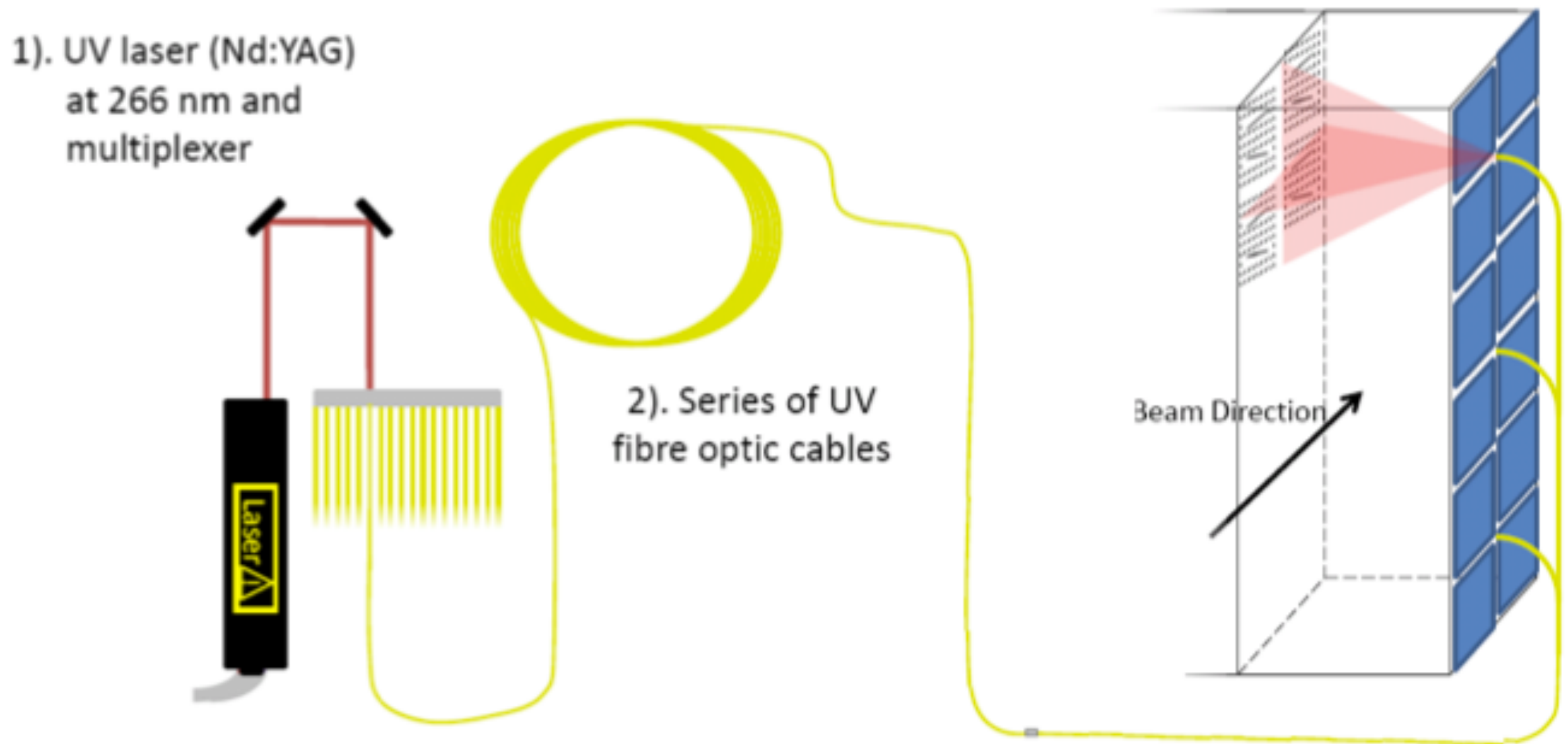
- MicroMegas micro pattern gas detectors



2% momentum scale goal with
mom. resolution goal of:

$$\delta p_{\perp} / p_{\perp} = 0.1 p_{\perp} [GeV/c]$$

Photo-calibration (laser) system



UV laser light illuminates Al targets on TPC cathode.
Motorized multiplexer couples light to 1 of 3 fibre optic cables.

Ejected photo-electrons drift full length and are read out

Photo-Calibration advantages:

- Redundancy, superiority as compared to cosmics:
 - Drift velocity (T2K: few ns for 870mm drift distance)
 - Gain of electronics
 - Transverse diffusion
- Diagnosis of T2K electronics issues (clock synchronization, HV problems)
- ~~Magnetic field distortions~~ (not applicable) Integrated along drift information about E field

Disadvantages:

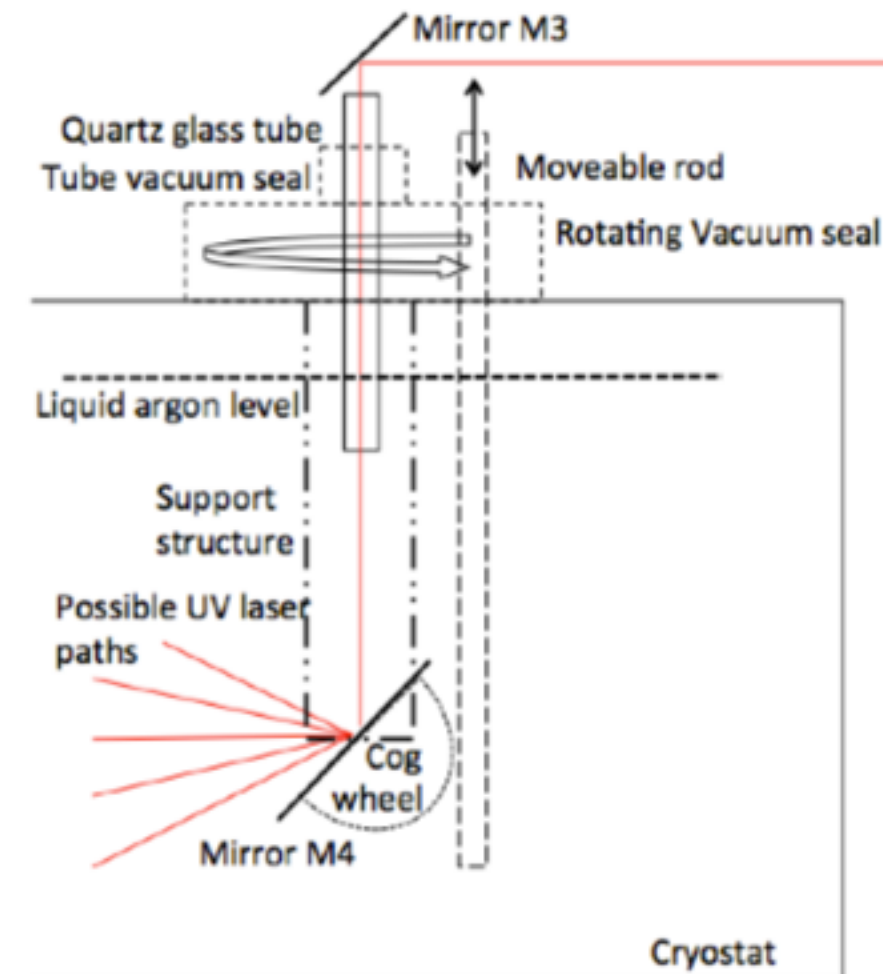
- Longevity: reduced laser operation time due to laser degradation
- **System only provides integrated E field**
- Would use existing penetrations and/or not penetrate the field cage

(Some) details in backup

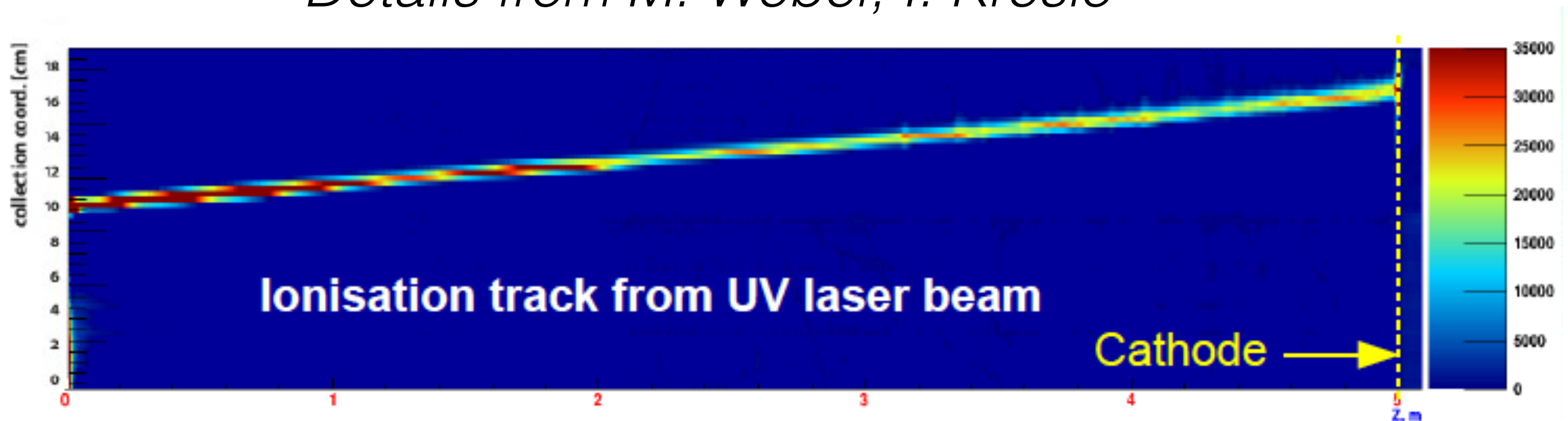
MicroBooNE, SBND laser system

Ionize the liquid Ar using Nd:Yag laser (266nm)

- Steerable mirror to alter path, crossing tracks for field map
- Straight tracks (no MCS, no delta rays), no recombination

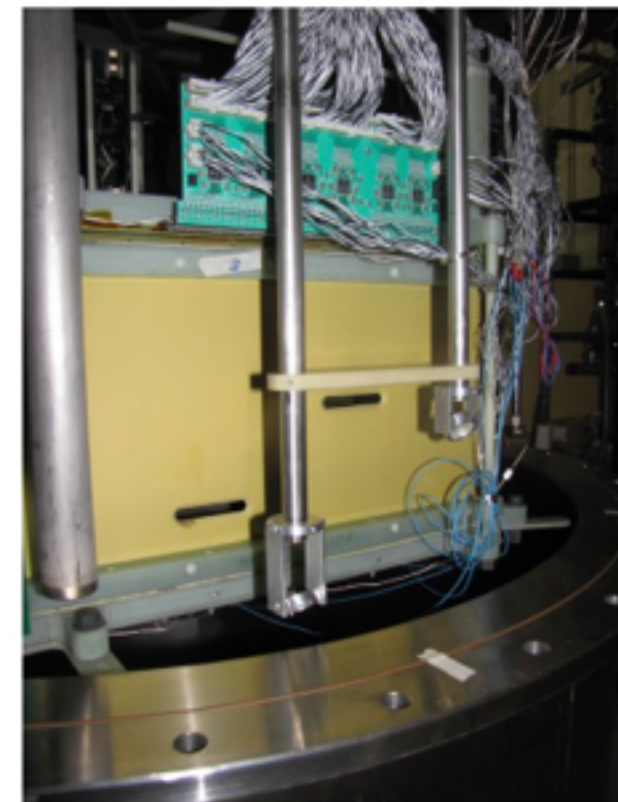
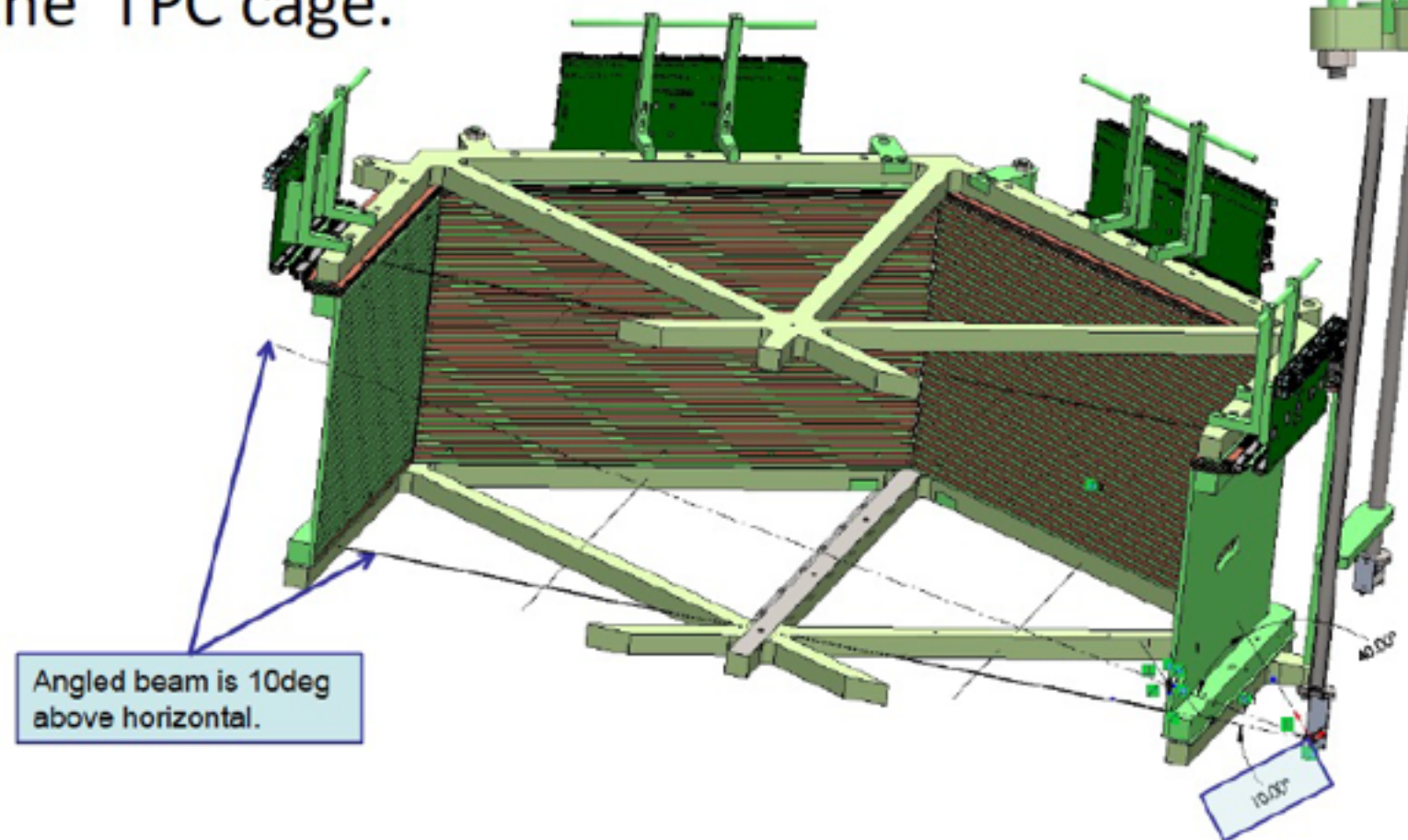
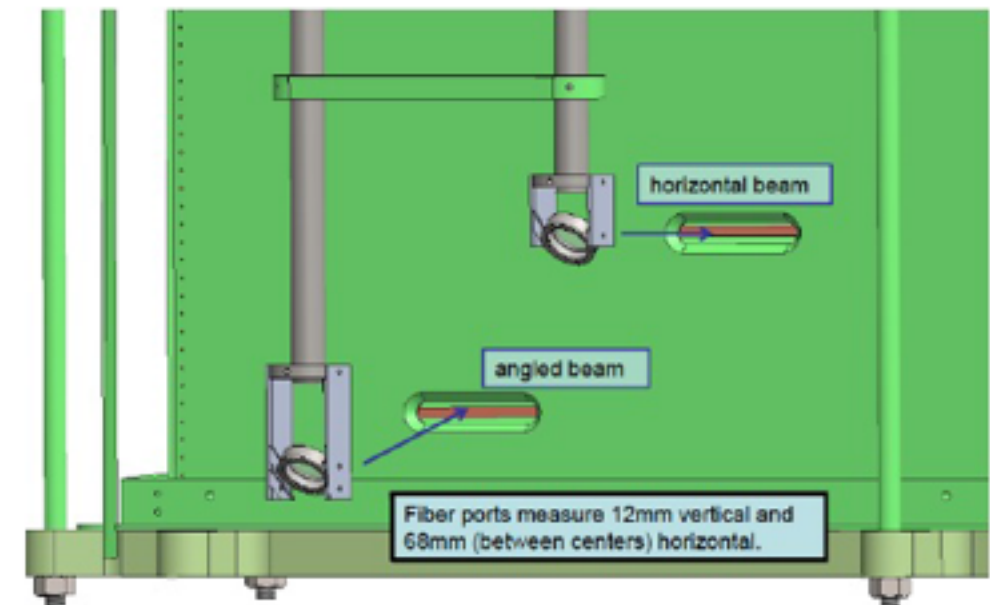


Details from M. Weber, I. Kreslo



Details of the laser system for CAPTAIN developed by LANL

- Laser beam is guided via mirror into the two periscopes
- Steerable mirrors at the bottom of the periscopes steer the beam through slits on the TPC cage.



Laser positioning system with fiber, PIN diodes

Details from J. Maricic: <https://indico.fnal.gov/event/16424/>

Advantages:

- Field map via crossing tracks
- Track reconstruction
- Charge density (dE/dx)
 - Commissioning wire response vs. time for cosmic on all wires
- Redundancy with purity monitors (charge attenuation)
 - electron lifetime measured in miniCAPTAIN
- Diffusion (track divergence), end track peak (longitudinal)
- Cross calib of light for photon systems?

Disadvantages, questions:

- Operation: what if the mirror gets stuck?
 - Multipurpose port planned, current design is replaceable and accessible (so far)
- Source of noise?
 - No effect yet seen yet
- Calib of photon systems not proven yet
- Burned FR4 in miniCAPTAIN

Observable ionization depends on:

M. Weber, mini-workshop: <https://indico.fnal.gov/getFile.py/access?contribId=9&resId=0&materialId=slides&confId=14909>

- Beam divergence: nominal 0.5 mrad
(can change at the mirrors!)
- Beam absorption: does not seem to be an issue...
 $\lambda_{\text{att}} > 100 \text{ m}$ at 266 nm
“Attenuation of vacuum ultraviolet light in liquid argon” , Eur. Phys. J. C (2012)
- Rayleigh scattering (40m at 266 nm)
- Refraction on density gradients
- Non-linear effects (Kerr-induced self-focusing)

What about MIP-like charge?

- Laser tracks are wider (5mm vs. 50nm) than cosmics
- But, charge on a wire is comparable to a MIP (integrated over 3mm)

Default system choice

- Assume we will do warm alignment survey (ala ICARUS)
- uB/SBND system allows for probing $E(x,y,z)$, sources of E field distortion produce localized or spatially varying effects
- T2K system is integrated field, uses same laser, different intensity, may be able to merge systems if integrated field is also desired

Laser penetrating the Field Cage Studies

- The Laser *may or may not* penetrate the Field cage (FC)
 - If we penetrate, it will be only for ports on the top of the TPC; not for the 8 ports outside the FC
 - The laser ports are currently located at 40 cm from APA
 - The ground plane starts 1 m away (in X) from APAs, so *we don't have to penetrate the ground plane*
- Bo performed some studies to understand how big E-field distortions are for a laser penetrating the FC

Laser penetrating the FC Studies

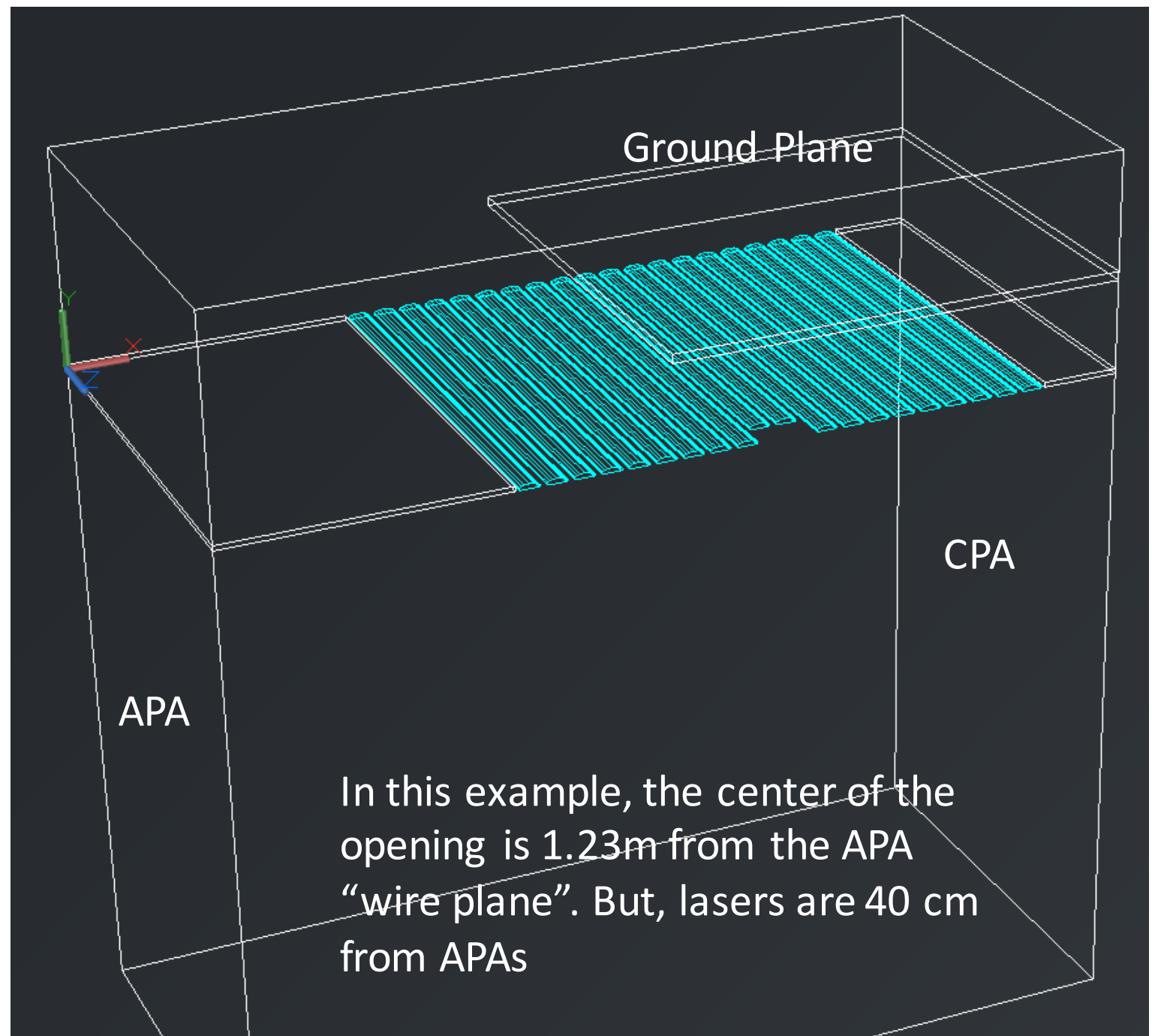
Model Geometry

Bo Yu

The field cage is modeled from 20 FC bars with discrete voltages and two plates with linear voltage gradient. Two FC bars are cut short by 7cm from the symmetry plane. The total opening for the laser head is 134mm x 140mm. The total drift length is 2m.

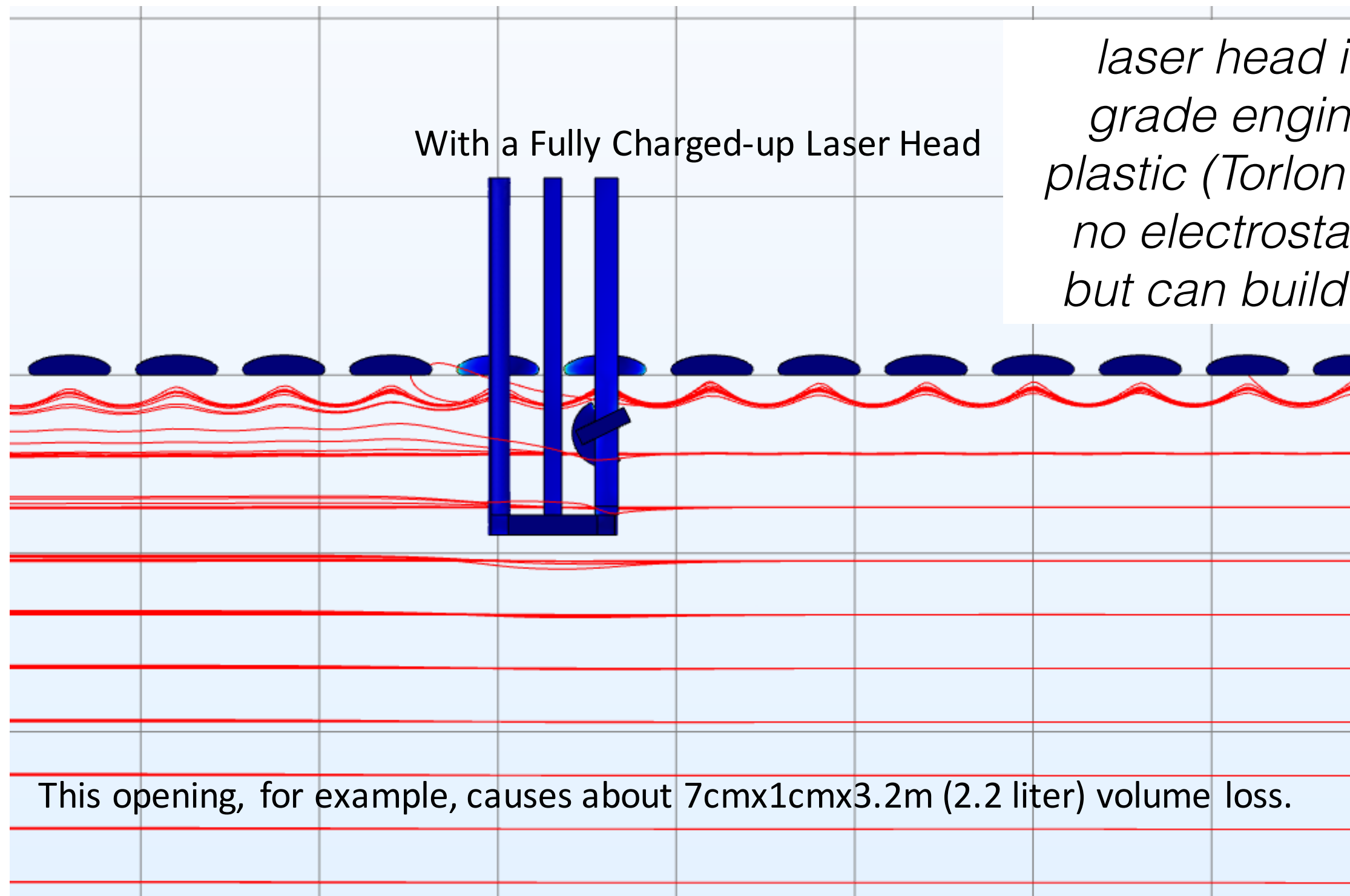
A ground plane with ProtoDUNE dimensions is added 20cm above the field cage. A necessary hole in the ground plane is not modeled. Its impact on the field inside the FC is minimal.

We have the option to move up the top FC such that the laser head is above the APA active volume



Opening at 0.4m from APA (Looking along the beam direction)

Bo Yu



<- APA

CPA ->

Alignment: Laser vs Cosmics

Calibration Quantity/Parameter/ Effect	Cosmics	Laser	Past Experience or Comment
APA-APA “local” alignment $\Delta x, \Delta z$	Need ~ 1 year of cosmics	Laser has sub- mm precision; scale of days	35-ton saw $\Delta x, \Delta z \sim 3\text{mm}$ with a precision of 0.05 mm
APA-APA “local” alignment (Δy)	may depend on cosmic angular distribution	Laser has broad angular coverage	—
All-APA global alignment	boot-strapped; certain modes not diagnosable	Laser tracks can cross multiple APAs	—
Motion of support structure	difficult/ impossible with cosmics?	Laser location and reproducible position constrain scenarios	—

Diagnosing failures & Stability Monitoring: Laser vs Cosmics

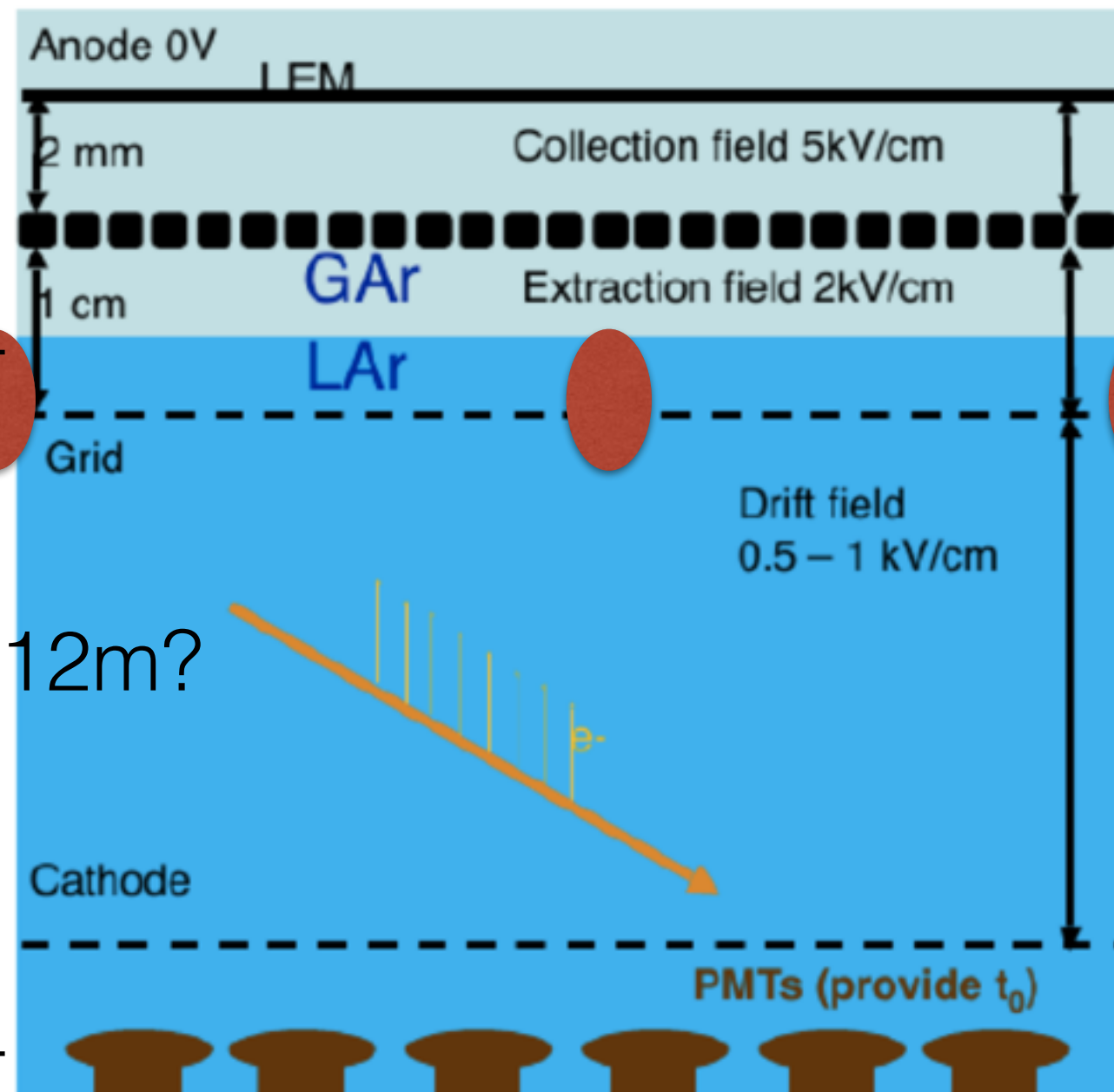
Calibration Quantity/ Parameter/Effect	Cosmics	Laser	Past Experience or Comment
Cathode Flatness	may take a year	Laser rapid	—
APA flatness	Possible with cosmics (e.g. arrival time differences) but may take years?	Laser rapid	+/- 0.5 shift is correctable
Failure of Electronics readout	Wait for cosmics to hit wire/region	Laser rapid	Preferred method: External charge injection; pulsing cathode etc.
Voltage variations across cathode	difficult/impossible with cosmics?	Laser only option?	highly unlikely event
Resistor Failure across a Field Cage	Wait for cosmics to go through the region	Laser rapid, can map out	—

E-field Distortions

Calibration Quantity/Parameter/Effect	E-field distortion	Spatial distortion	Impact on dQ/dx (via recombination)
CPA misalignment (+/- 1 cm displacement at the CPA)	~1%	7 mm	—
CPA structural (e.g. CPA plane bows) gentle deformation	~0.2%	—	—
Resistivity on dividers not uniform; sorting order	large changes in E-field	—	—
Penetrating Field Cage for Laser (e.g. SBND model)	will penetrate near APA; Laser head made of plastic, so no electrostatic risk; E-field distortions expected to be small	—	—
Space charge from cosmics (for both SP/DP)	negligible	negligible	—
Space charge from Ar39 (SP)	0.1%	1 - 1.5 mm	0.03% & <0.1%
Space charge from Ar39 (DP)	1.0%	5 cm	<0.3% & 2-3%

Dual Phase considerations

Concept of double-phase LAr TPC (Not to scale)



- E field distortions due to space charge potentially an issue
- Gas-liquid interface may have varying charge
- Laser placement similar to SP to provide spatial E information (no detail FT discussion yet)

Key questions (1)

1. *What are the possible configurations for a laser system, and what are the physics reach of each?*
 1. Likely direct ionization is needed for the spatial dependance of E field distortions
2. *What would a realistic run plan be for calibration? How long for a laser scan? How often deploy the laser (and why?) What are the associated DAQ needs?*
 1. Discuss in DAQ session tomorrow
3. *Are there any benefits to the laser system for Supernovae?*
 1. E field distortion important for E scale, etc

Key questions (2)

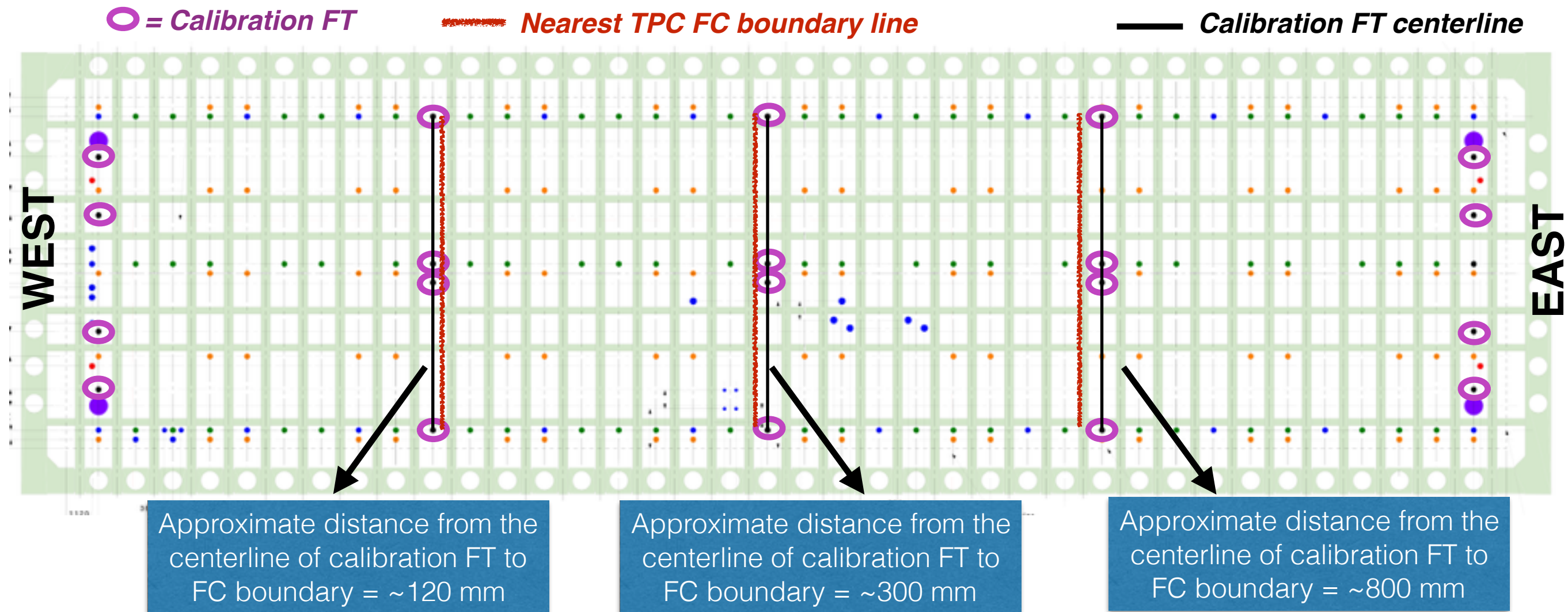
1. *What are the timescales for the electric field variations?*
2. *(Comment from lessons learned). Is there a plan to do a warm survey of detector before filling?*
 1. Yes, was valuable to ICARUS
3. *and survey after cooling to see whether detector components behaved as expected?*
 1. Could be valuable for some structural deformations under cooling (but not fluid flow), but feasibility needs thought
4. Do you have more realistic estimates of statistics/timelines for Laser vs Cosmics?
 1. Discussed in talk

Key questions (1)

1. What are the possible configurations for a laser system, and what are the physics reach of each? -> Discussed
2. What would a realistic run plan be for calibration? How long for a laser scan? How often deploy the laser (and why?) What are the associated DAQ needs? -> DAQ session
3. Are there any benefits to the laser system for Supernovae?
4. What are the timescales for the electric field variations?
5. (Comment from lessons learned). Is there a plan to do a warm survey of detector before filling? and survey after cooling to see whether detector components behaved as expected?

Backup

Calibration Feedthroughs

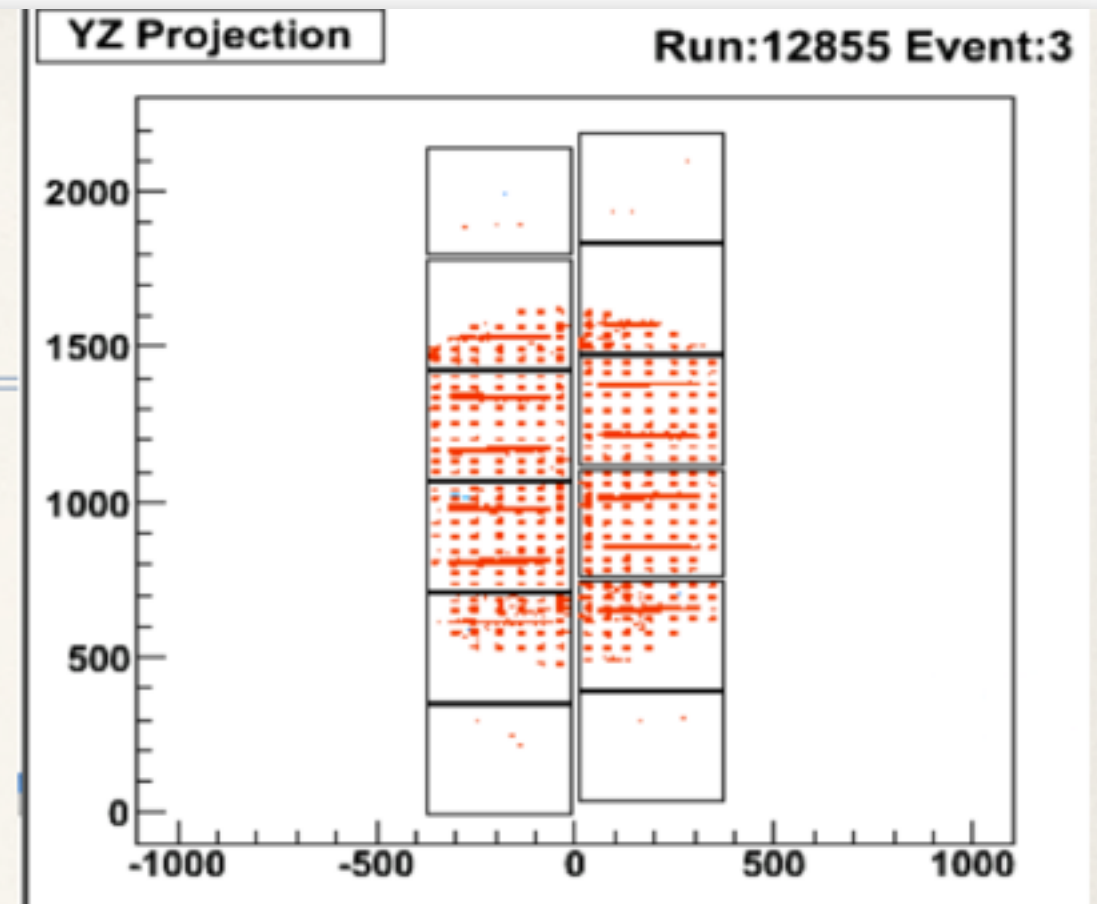


- Since the cryostat design process is still being finalized, the position of FTs might shift 100 mm East or West;
- The TPC position also has some flexibility to shift east or west.
- There is no perfect position for all FTs to align at the same distance from the breaks b/n TPC elements

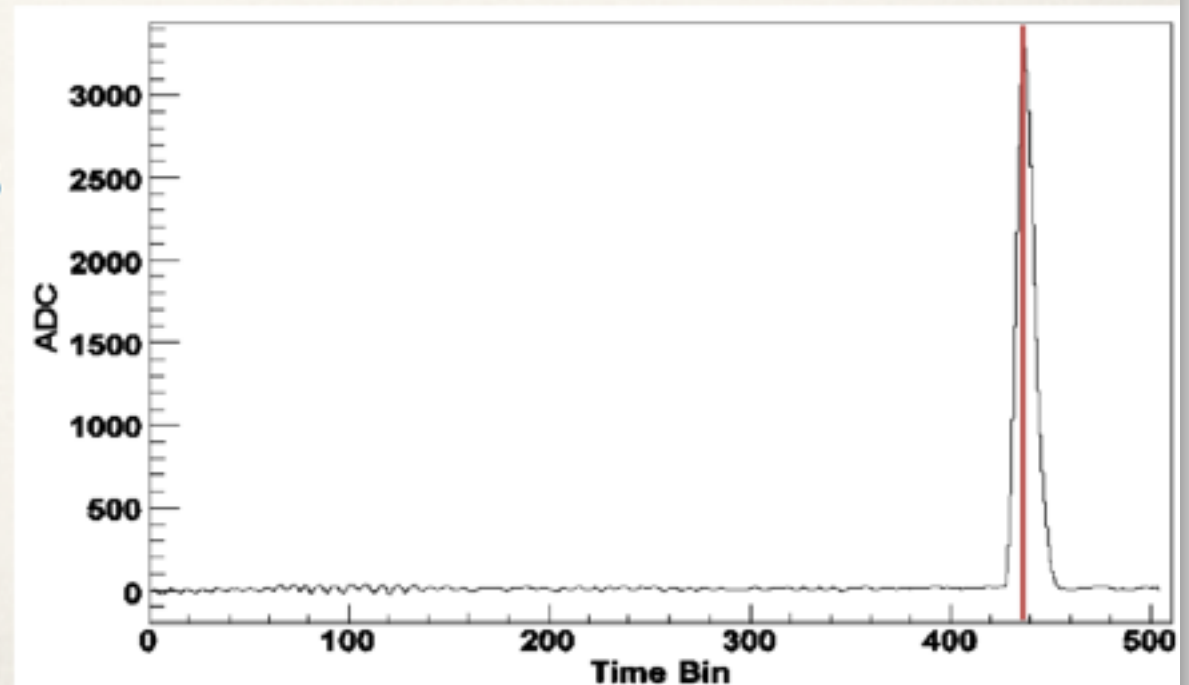
T2K laser information (C. Bojecho)

Laser Data.

- * Good separation between Al and Cu.
 - * Al 2 photo-e/mm²
 - * Cu 0.03 photo-e/mm²
- * Time difference between laser trigger and arrival time signal gives precise measure of drift velocity.
- * Combining channels gives resolution to a few ns.

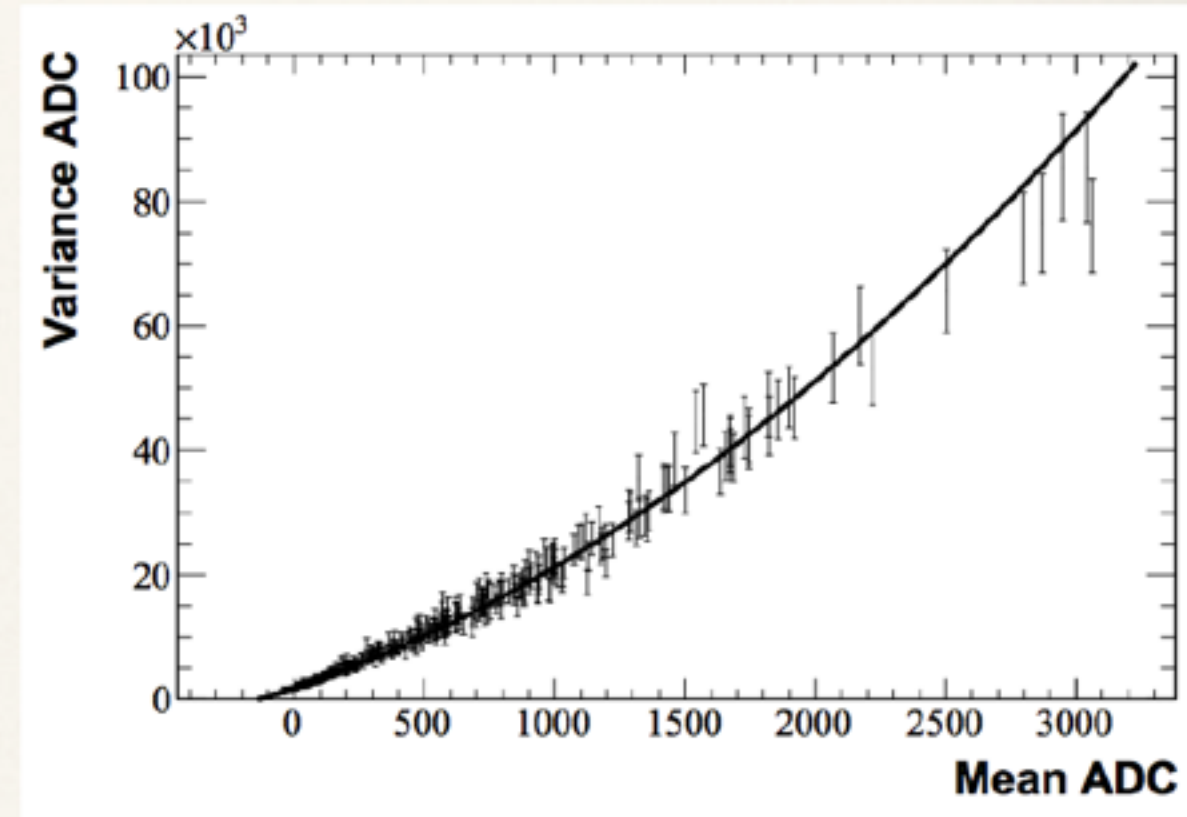


Single laser flash from centre fibre



T2K laser information (C. Bojecho)

- ❖ Variations in amplitude of signals from repeated measurements is due to photoelectron and gain fluctuations.
- ❖ Repeated measurements of a single Micromegas, variance vs mean ADC is quadratic. Linear term gives gain constants.
- ❖ Gain of ~ 8 ADC/photo-e. Used as cross check to other calibration sources (MIPs).



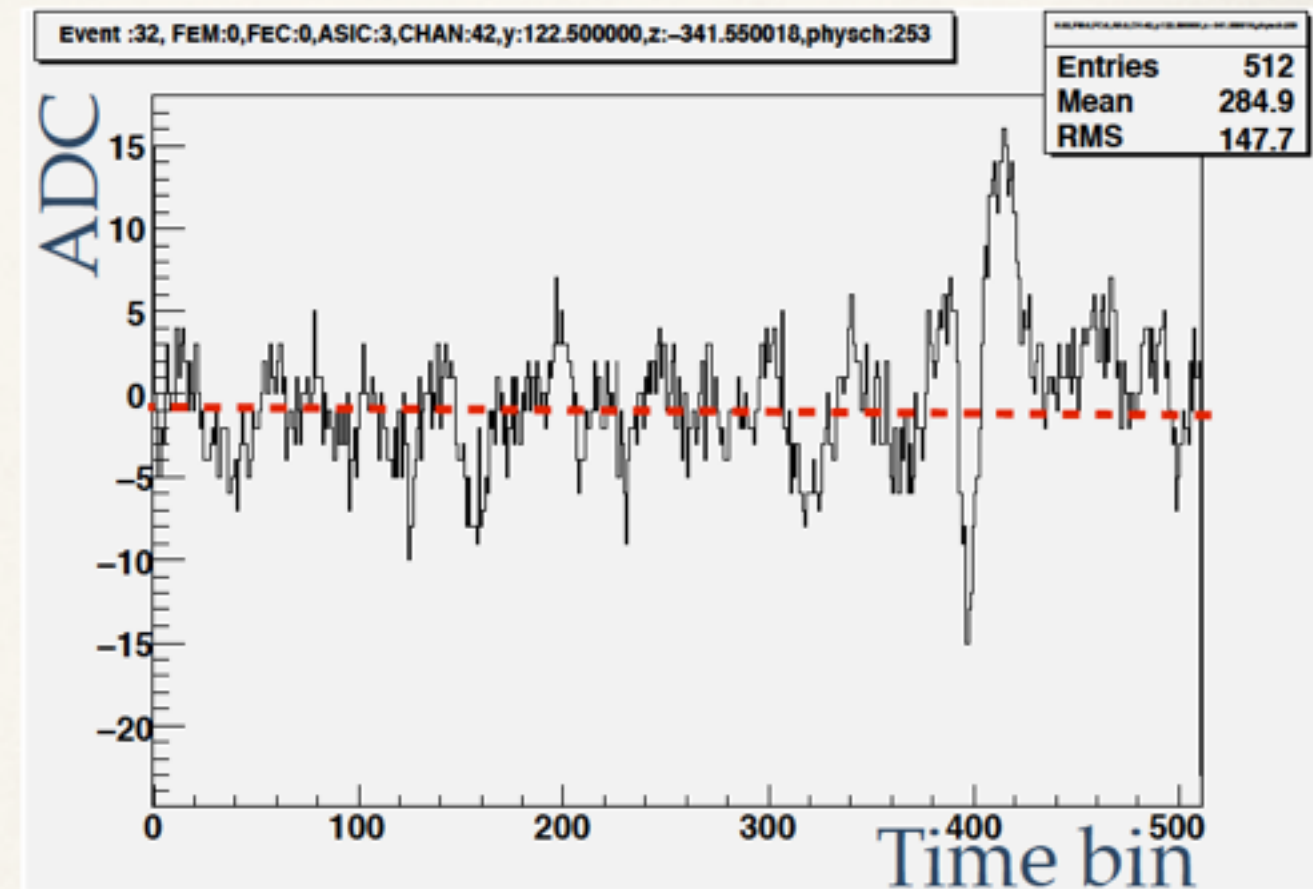
T2K laser information (C. Bojecho)

- ✧ Fit distribution of charge from strips to give an estimate of transverse diffusion.
 - ✧ Compare width of charge distribution at readout plane to physical strip width.
- ✧ Some strips give very high values of transverse diffusion.
- ✧ Background from copper could cause diffusion to be overestimated.
- ✧ Strips with smallest diffusion measurements still 20% larger than measurements from particle tracks.

T2K laser information (C. Bojecho)

Negative Polarity

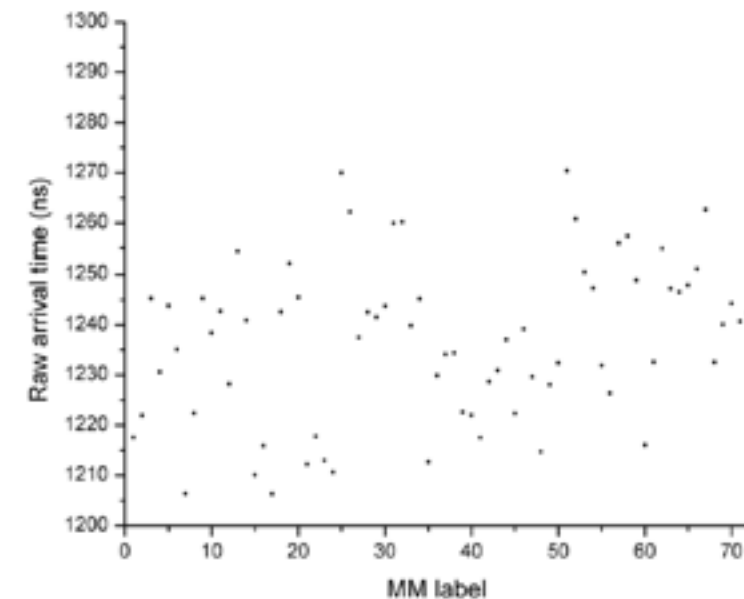
- ❖ Laser events - large amount ionization arriving at once.
- ❖ Can cause opposite polarity amplitude in waveform.
- ❖ Magnitude of opposite polarity is measure of capacitance between mesh and pads.
- ❖ Has helped diagnosis of HV filter problems.



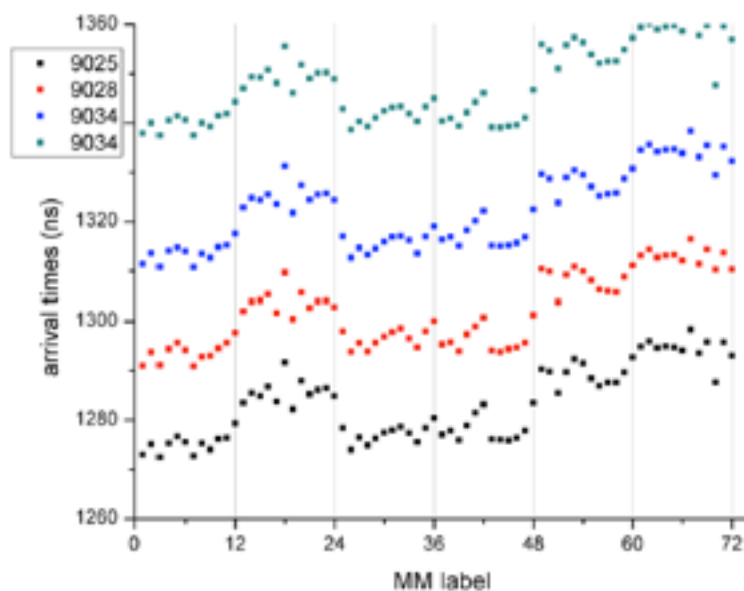
T2K laser information (C. Bojecho)

Arrival Times

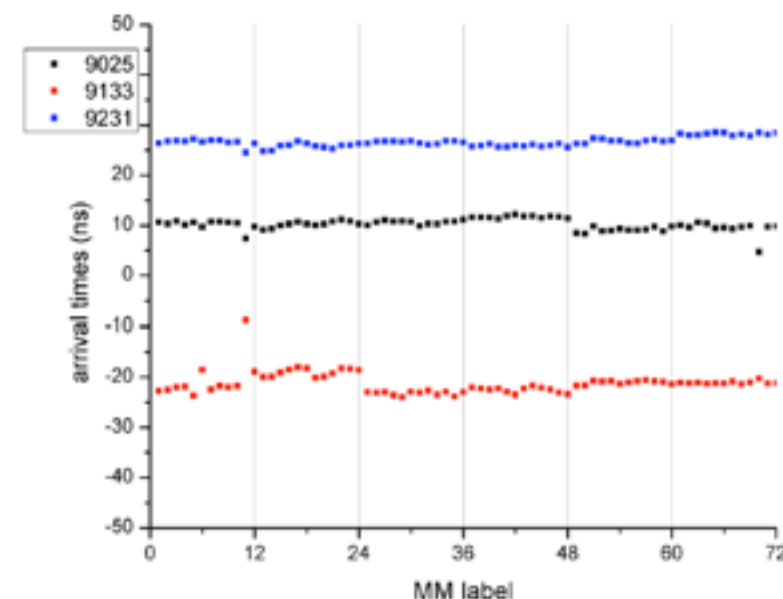
- ❖ Arrival times from laser is useful check of timing offsets across the TPC.
- ❖ Time offsets can change after power cycling of electronics.
- ❖ Measurement laser data arrival times.



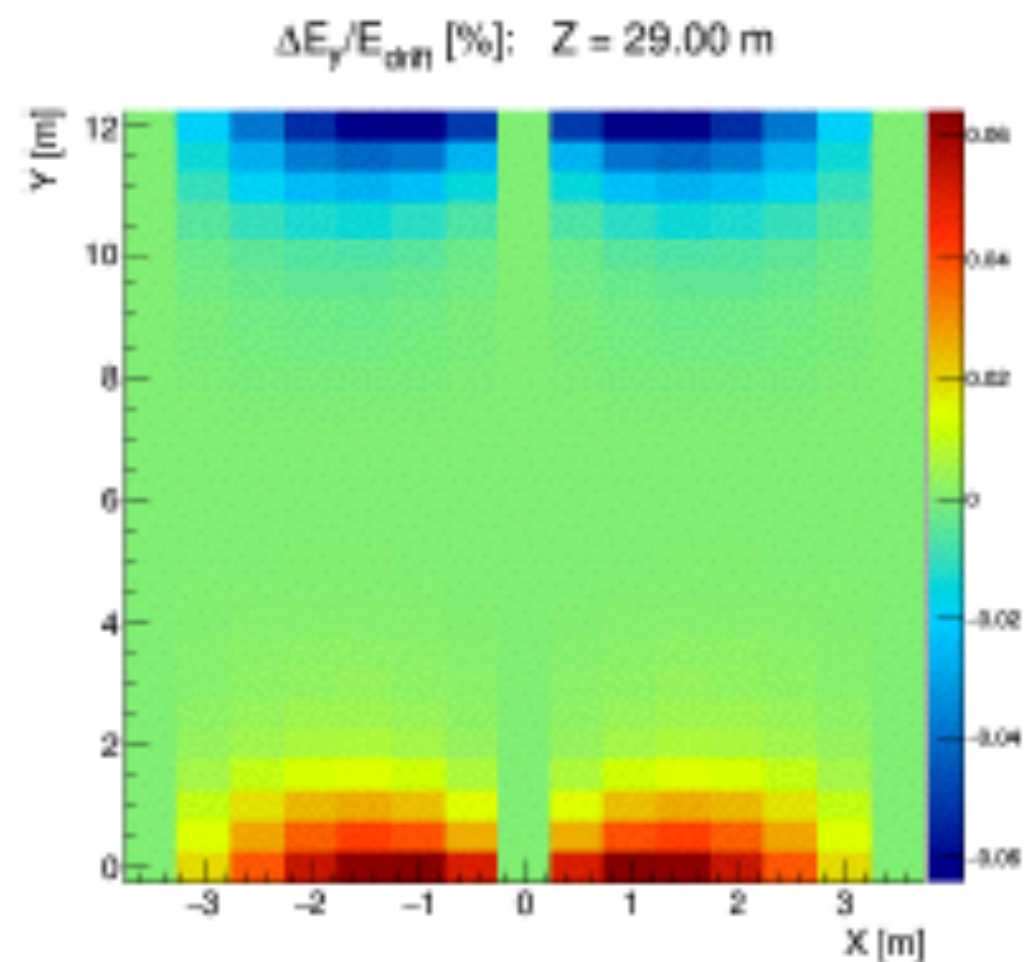
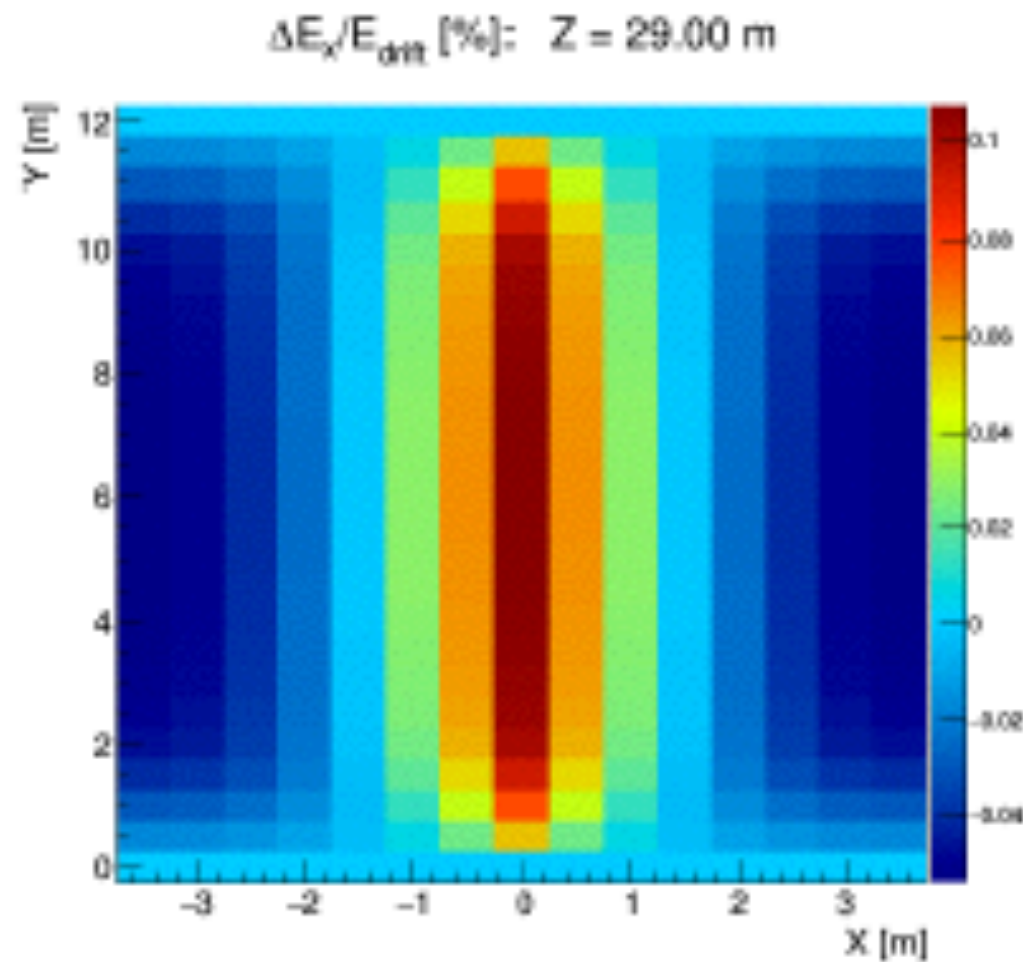
raw laser arrival times



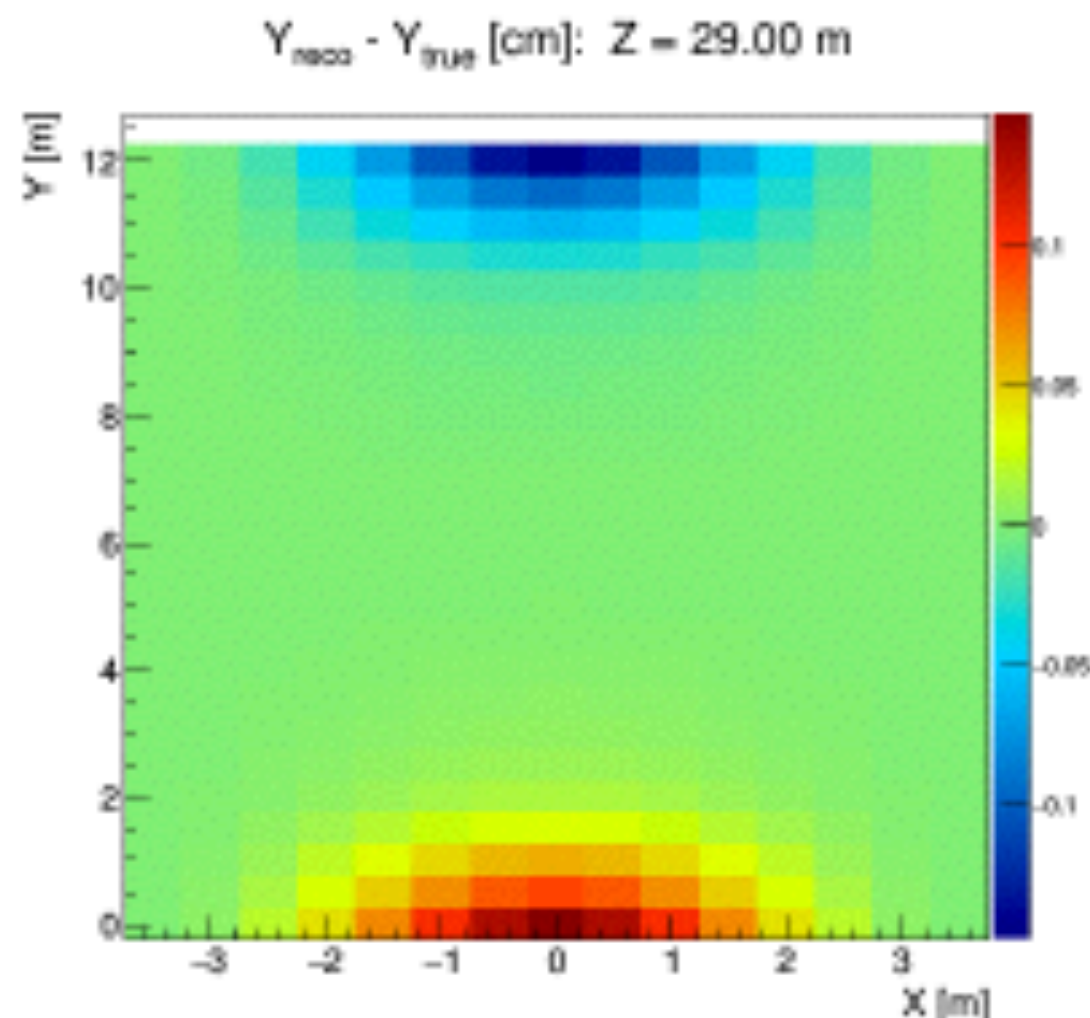
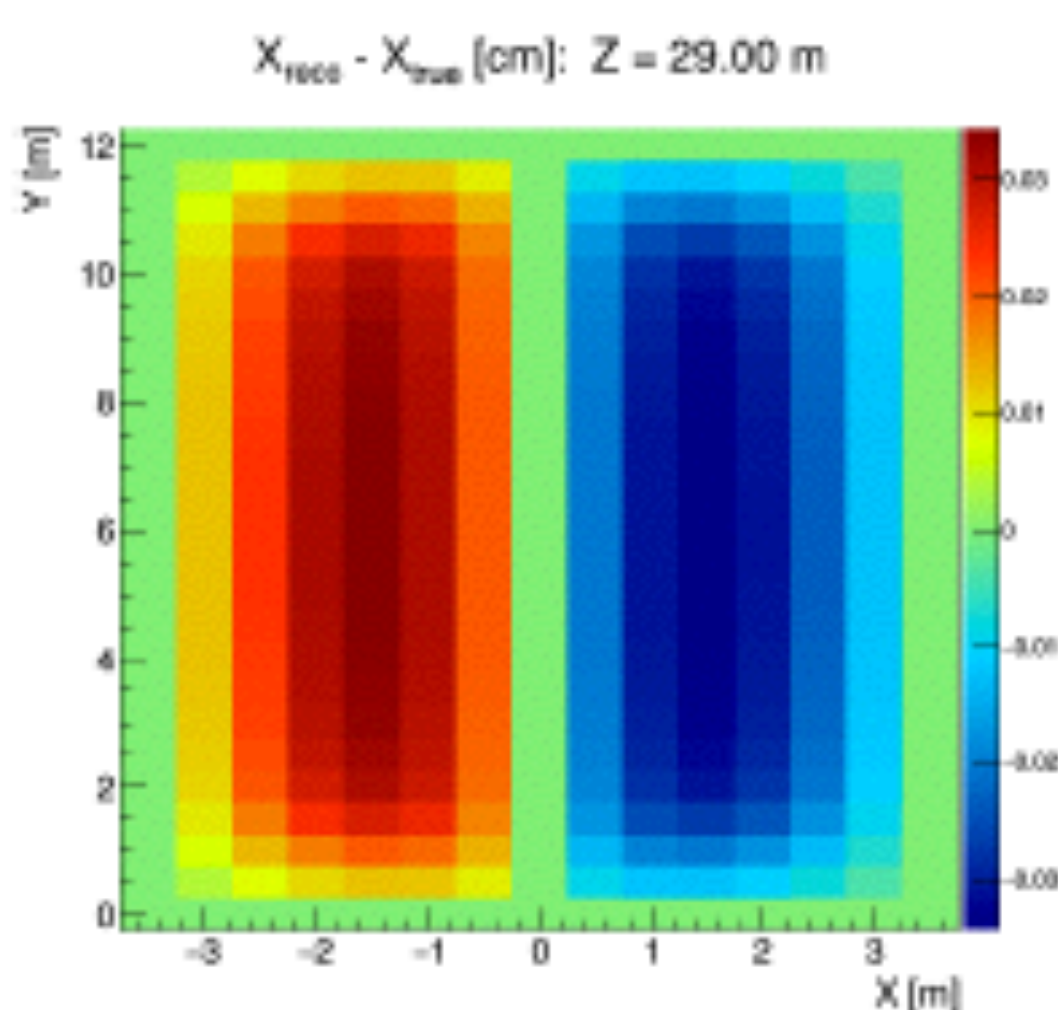
after cosmic calib



after removing pattern due to negative polarity



- ◆ DUNE SP FD – looking at one half of central Z slice
 - APA+CPA+APA
- ◆ E field distortions on order of **0.1%** – very small!
 - Impact on dQ/dx from recombination \sim **0.03%**



- ◆ DUNE SP FD – looking at one half of central Z slice
 - APA+CPA+APA
- ◆ Spatial distortions on order of **1.0-1.5 mm** – very small!
 - Total impact on dQ/dx (including recomb.) **< 0.1%**

M. Mooney

TPC Calibration

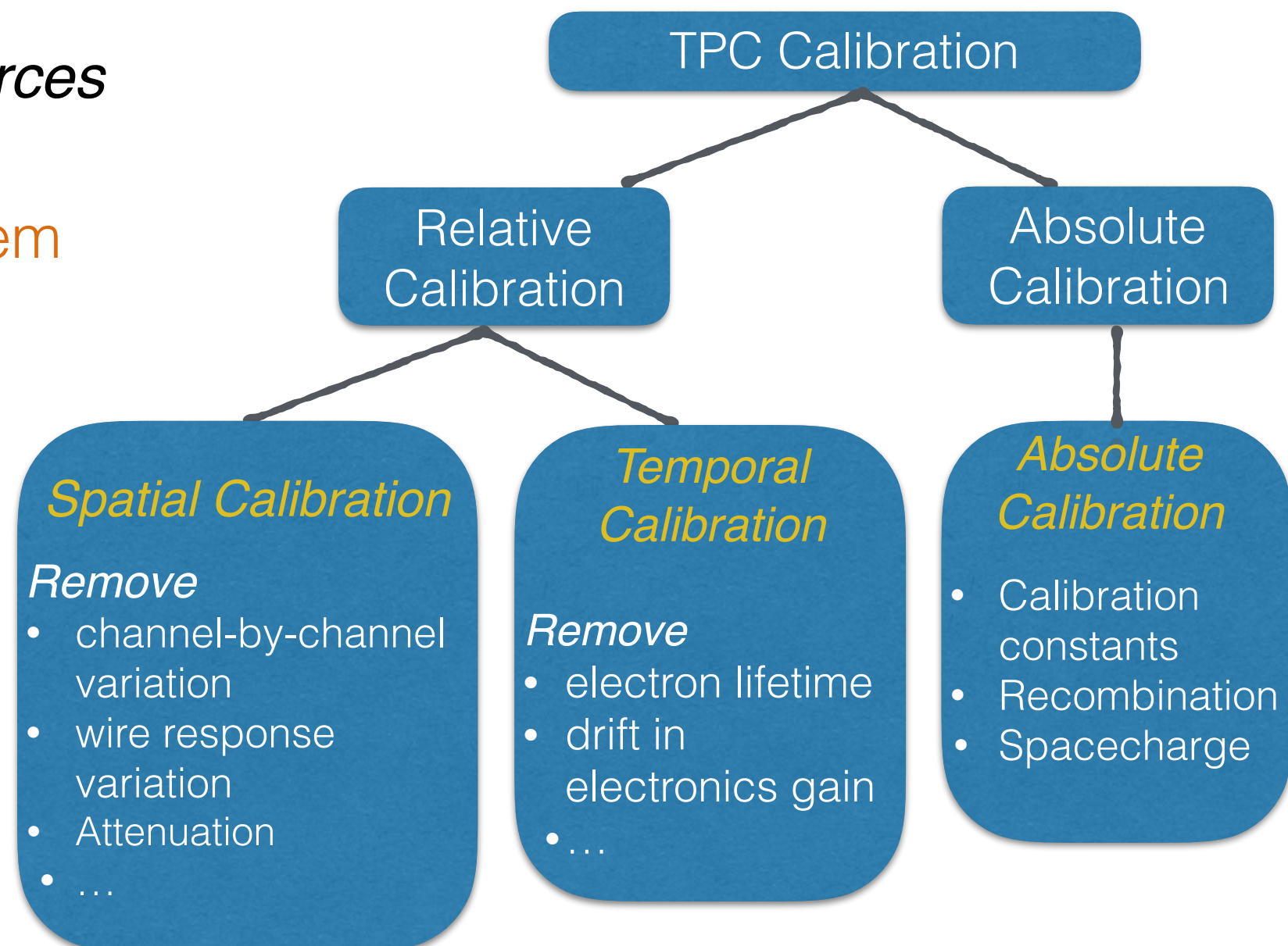
Goal: Achieve uniform detector response in space and over time and provide reliable energy information for physics analyses

Possible Calibration sources

- Charge Injection System
- Cosmic muons
- Laser system

<https://indico.fnal.gov/event/15240/contribution/1/material/slides/0.pdf>

T. J. Yang



TPC Spatial calibration

- *Channel-by-Channel Calibration:* remove gain variations
 - Can use charge injection system to remove gain and linearity of each channel; uB: 1-2% variation. [Laser useful here](#)
- *Wire response Calibration:* non-uniformity in response due to shorted/touching wires
 - Cosmics — statistically challenging for DUNE to do this; [Laser can be very helpful here](#)
- *Attenuation Calibration:* Attenuation along drift due to impurities
 - uB saw excellent purity, measurement using cosmic ray Anode-Cathode crossers
 - One can combine all cosmic rays for this calibration
 - [Laser system is potentially good for this calibration](#) (arXiv:1304.6961)
 - Another potential source: [Ar-39](#)

Absolute Energy Calibration

- Once spatial effects are removed, use cosmic rays or laser (if response well understood) to remove temporal variations
- Absolute energy calibration (convert dQ/dx to dE/dx)



- Standard handle: Stopping muons
- Can combine stopping muons over several months or a year to get needed statistics. **Laser partially helpful**
- Many other issues: angular dependence of dQ/dx ; dE/dx separation b/n tracks and showers at the start; reconstruction vs detector/physics effects,...